ÖSCAR GRIMM describes Bacteria and Vibriones from his own investigations in the *Archiv fur Mikrosc. Anatomie.* He has observed their conjugation and fissiparous multiplication, and also has seen leucocyles breaking up into granular matter which ultimately assumed the form of Bacteria.

PROF. MOLLER, of Lund, Sweden, has published the Ephemerides of Faye's comet for its next return to the neighbourhood of the sun. It will be in perihelion about July 18, and will continue to approach nearer and nearer to the earth till Jan. 10, 1874. It will not, however, be in a position favourable for observation, and it is very probable that not even the most powerful telescope will be able to catch it.

M. CALLAS in *Les Mondes* endeavours to account for a dry haze (*brouillard sec*) which is seen in the atmosphere at certain seasons in particular countries. At Paris he says it is clearly visible on the horizon on the morning of lovely summer days, and is regarded as the presage of fine warm weather. It is of a light roseate hue. In proportion as the day is dry and warm, the denser and higher above the horizon is the haze. This haze is seen at all heights, having been observed by Saussure in Switzerland, by Lecay and Charles Martin in Auvergne, and by Wilkomer in Spain; in all cases, the phenomenon is seen at its best when the day is dry and warm. M. Callas attributes it to the combustion of aerolites and shooting stars. The attraction of the earth, he says, causes these bodies to deviate from their regular course and to be precipitated to the earth's surface with a rapidity which certainly exceeds 20 kilometres per second, and which is sufficient to set them on fire and render them volatile. The vapours thus produced rapidly become so rarified that they may be looked upon as the ultimate limit of divisibility of insoluble bodies and form the dry mists alluded to. Obeying the law of gravity these descend to the earth from the heights where they are formed, slowly however, on account of their extreme tenuity. As they approach the earth they come under the influence of winds which dissipate them, and of cold moisture, which absorbs them. Hence it is that they are perceived only in certain countries and in warm seasons; especially in Spain, and on the table-lands of Abyssinia and Mexico. M. Callas thinks that the haze may be regarded as a sort of cosmical matter akin to that which composes the tails of comets. The hypothesis has the merit of being at least curious, and so far as we know, original.

THE first paper in the last number of the Bulletin of the French Geographical Society is in connection with a well-executed map of the chief physical features of Eastern Brazil, appended to the number. M. Charles Grad contributes a long article on the geology of the Algerian Sahara and its system of waters. Perhaps the most interesting article is by M. Paul Gaffanel on the Great Sargasso Sea in the middle of the Atlantic, the history of which he traces from the Phœnicians downwards, describes its geography historically and with reference to what is known of it at present, which seems to be comparatively little, and concludes by pointing out that the wrack or algæ of which it is composed might be put to immensely profitable industrial uses.

WE have received the prospectus of the new Italian Geographical Magazine, whose first appearance we announced last week. Dr. Petermann has written a very hearty preface for his young friend, the editor, Guido Cora, whose plan is very comprehensive, embracing not only geography proper, but also geognosy, botany, zoology, anthropology, ethnography: hence the name of the magazine,—*Cosmos*. We wish it ample success.

THE *Revue Scientifique* for Feb. 8 contains Dr. Liebreich's Royal Institution lecture on the effect of School Life on Vision in the Young.

SIR W. ARMSTRONG ON THE COAL QUESTION*

II.

AT the present moment attention is being drawn to a new method of increasing the efficiency of the steam engine by pumping heated air into the boiler. It is impossible to conjecture what theoretical considerations could have led Mr. Warsop, the discoverer of the system, to anticipate beneficial results from the adoption of such an expedient, and yet the experiments that have been made in proof of its efficacy are so authoritative that they cannot be repudiated on the ground of their being unsupported by theory. This subject, although much debated of late, is still so ambiguous and obscure that I shall take the present opportunity of stating the difficulties of the case in the hope of eliciting satisfactory explanation. Mr. Warsop's method consists in attaching to a steam engine a forcing pump for the purpose of injecting air into the boiler. The pipe from this forcing pump is formed into a coil in the flue so that the air may absorb a portion of the waste heat. After entering the boiler the pipe is laid along the bottom, and being perforated with holes allows the air to bubble up through the water at many different points. The result appears to be that, with a given expenditure of fuel, the available power of the engine is considerably increased by the action of the air-pump, notwithstanding that the power for working it is derived from the engine itself. How, then, is this to be explained? It is clear that air forced into a receiver cannot without the aid of extraneous heat give back all the power expended upon the forcing pump. There must of necessity be loss of power by friction, and also from the impossibility in practice of realising all the expansive action of the condensed air corresponding to the compressive action of the pump prior to actual injection taking place. It would be a liberal estimate to assume that one-half of the power expended on the pump is recoverable from the air. Hence, to make up the deficiency by the application of heat, we should have to double the volume of the air, which would require it to be heated to upwards of 500° F, above its initial temperature. Now, in the case of the Warsop arrangement, considering the inconsiderable heating power of the escaping gases to which the air-pipe is exposed; considering also the slow absorbing power of air, and the smallness of the surface presented by the coiled pipe, it is hard to believe that the air could enter the boiler at such a temperature as I have named; but even if it did, where is the surplus power to be found that gives the engine a palpable increase of efficiency? The mere reaction of the compressed air, with all the aid it can possibly derive from the absorption of waste heat, would barely save a loss, and certainly could never account for an important gain. It seems obvious, therefore, that whatever beneficial action is exercised by the air must be of an indirect nature, and not the immediate effect of its mechanical energy.

Four modes of action have been put forward to account for the effects obtained. Firstly, it is said that the air, in bubbling through the water, facilitates the disengagement of the steam. This may very possibly be the case, for we know that water, entirely deprived of air, may be heated in an open vessel to a temperature greatly exceeding the usual boiling point, before ebullition commences. The reason of this is, that the adhesion between the water and the containing vessel, and also between the particles of water themselves, is sufficient to restrain the formation of steam at the usual boiling heat, unless air be present to afford points of separation. So far the explanation is plausible; for if the abstraction of air from water raises the boiling point, we may infer that the addition of air will lower it. But the reduction of the boiling-point within any supposable limits, would not lessen the quantity of heat required for the production of the steam sufficiently to afford a solution; because the sum of the latent and sensible heat, though not constant, as was formerly supposed, does not vary in relation to the boiling point to such an extent as would account for any important saving in that direction. A tangible advantage might, however, accrue from the accelerated transmission of heat from the fire to the water, caused by the increase of difference which a lowered boiling point would occasion between the temperature of the water and that of the fire and gases acting on the boiler; but in the absence of thermometric experiments to show how much the boiling point is actually reduced, and how much the escaping gases are cooled, it is impossible to form any definite opinion as to the amount of this saving. It is certain, however, that unless the reductions of temperature be greater than can be readily conceded, they will not be sufficient to account for so large an economy as is said to be realised.

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* Continued from p. 272.

Secondly, it is argued that the bubbles of air virtually afford an extension of heating surface. So they do, in relation to the heat carried in by the air; but the air can only part with its heat by lessening its direct contribution to the power of the engine. Moreover, if the heat carried in by the air be insignificant in quantity, as I believe it to be, the explanation fails in every point of view.

Thirdly, it is stated that the action of the air prevents and even removes incrustation, and thereby keeps the heating surfaces free from all obstruction as regards the transmission of heat. Very careful observation would be required to establish this fact; but, granting the fact, it would follow that the advantage of injecting air would be limited by those cases in which deposit would otherwise be formed. In a boiler perfectly free from incrustation the injection of air ought to be nugatory, but this does not appear to be the case.

Fourthly, it has been ingeniously suggested by Mr. Siemens that the air passing with the steam into the cylinder may form a film on the interior surface capable of arresting, in a great measure, that condensation which is known to be so wasteful of power in unjacketed cylinders, where the steam is used expansively. It is highly probable that the air would really accumulate in this manner against the sides of the cylinder; because, while the particles of steam sank down into water, the particles of air would remain. It is also pretty clear that this film of air would intercept the abstraction of heat by the cooled material of the cylinder; but if we admit this mode of action, then it would seem to follow that it is only in the absence of a steam jacket to the cylinder that the economy of injecting air is realised, and in fact that the injection of air is merely a substitute for steam jacketing. Moreover, if such be the action of the air, pumping into the steam should, in this point of view, produce the same effect as pumping into the water.

I have dilated upon this subject more, perhaps, than necessary, but I have done so with a view to stimulate action in the matter, for it is time that the doubts and obscurities which beset the system should be cleared up, and its adoption or rejection be brought to an issue. There is no class of steam-engine in which economy of fuel is of so much importance as it is in marine engines, for not only is it an object in steam navigation to diminish the cost of coal, but it is a still greater object to save room, and thereby increase the space available for cargo. The introduction of compound engines has enabled steam to be used of much higher pressure than formerly, and with greatly increased expansive action. The result has been a saving of about 50 per cent. in the consumption of coal, and I believe I am substantially correct in saying that in steam vessels, employed on long voyages, this saving of coal has been attended with a fourfold increase of the previous carrying power. It is highly probable that still further reductions of fuel will be effected by following in the same path, which has already lead to such great economy. The pressure of steam in marine engines is still far inferior to that which is used in locomotive engines, and there is no obstacle, of an insurmountable nature, against the expansive action being increased proportionately to any further increase of pressure.

But our efforts to increase the efficiency of marine engines must not run too much in one groove. Recent improvements have been almost exclusively directed to the mode of *applying* the steam, and but little attention has been paid to the mode of *producing* it. The engine has advanced enormously in improvement, but the boiler has actually receded; for we now get less evaporative effect from marine boilers than was obtained from those previously in use. This diminution of effect has resulted from changes made in the form of the boiler, to enable it to resist the greater pressure of the steam; but there is no inherent necessity for sacrificing evaporative power to meet this requirement, as is proved by the example of the locomotive boiler, which, while it produces steam of double the pressure of that supplied by marine boilers, stands unrivalled in regard to evaporative effect. The superiority of the locomotive boiler in regard to evaporating power is chiefly due to the large capacity of its firebox, which affords ample space above the surface of the fuel for perfecting the combustion of the gases. In the old form of marine boiler the flame space above and beyond the fire was also very large, and the evaporation per pound of coal was nearly as great as in the locomotive. But this advantage has been sacrificed in the modern form of boiler, by adopting a cylindrical fire chamber within the boiler. This form is very favourable to strength, but it affords very little head-room over the fire, and the consequence is that, although the tubular heating surface is relatively as great as before, the evaporation per pound of coal has fallen considerably. I do not say that the locomotive form of boiler, pure and simple, is that which ought to be adopted for marine engines, but it is well worth consideration, whether by adopting the same principle of construction, a more efficient boiler would not be obtained for marine engines. A more powerful draught would probably be required than is now necessary, but this could be obtained by known mechanical methods, applied either to *draw* air through the furnaces, or to *force* it into a closed stoke-hole. The production of draught by auxiliary power, would have the great advantage of enabling the rate of combustion to be regulated at pleasure, so as to meet the varying demand for steam, and it would also facilitate the application to marine boilers of mechanical firing, which does not succeed with a slow draught, and requires a variable draught to meet the fluctuating production of steam required at sea. The great number of stokers required in large steamers, the severity of the work, and the inefficiency of the method they pursue, as evidenced by the dense clouds of smoke they produce, render the introduction of mechanical firing in such vessels a matter of the utmost importance; and I do not believe that any of the difficulties which appear to stand in the way are incapable of removal.

I must not dismiss the subject of steam power without some allusion to its application to agriculture. In no description of steam-engine has economy of fuel been more perseveringly and successfully followed out than in engines for agricultural use; and Mr. Bramwell, in his late address to the Mechanical Section of the British Association, does full justice to the mechanical engineers who have been the means of bringing these engines to such a high degree of efficiency. It is satisfactory to see that the application of steam to the cultivation of the land, and to every kind of farming operation, is rapidly extending; for if the food producing power of the land has to be increased, it must be by substituting, as far as possible, the comparatively cheap power of steam, for the labour, both of men and horses. The greatly increased demand for labour in manufacturing occupations, as well as for mining and constructive purposes, will certainly diminish the supply of rural labour and increase its cost. Such a result is not to be regretted, considering how miserably ill requited farm labour in most parts of England has been; but unless the growing cost of agricultural labour and of horse work can be counterpoised by a more extensive use of steam power, we may expect much of the land in this country to be thrown out of cultivation. Very different are the views of those who maintain that food would be more economically produced by increasing, instead of diminishing, the labour employed on the land. Such is the doctrine of those who advocate the parcelling out of the land in small plots to peasant holders, and who even contend that waste lands, incapable of profitable return by ordinary treatment, could, by this means, be advantageously cultivated. It would, indeed, be a retrograde step to renounce the aid of capital and mechanical skill in tillage, and fall back upon the primitive system of spade husbandry. If there be a country in the world where such a mode of cultivation is the best, that country is assuredly not England, where all the resources of science and skill are necessary to the maintenance of a large population, under adverse conditions of soil and climate, and where labour is more highly paid in manufacture than in agriculture.

I have had considerable personal experience of steam cultivation, and am a thorough believer in its efficacy; but I may here draw attention to a very general subject of complaint concerning the machinery and implements employed for the purpose. I refer to the frequency of breakages due to insufficient strength in the construction. If makers of the apparatus, used in all the varieties of steam tillage, could only be induced to be more liberal in the use of material, the introduction of their machines would be very greatly accelerated.

I must also touch upon the subject of steam traction on common roads, which has lately received a considerable impulse from the introduction of Mr. Thomson's invention of India-rubber tyres. The number of horses in this country is enormous, and being great consumers of food, their maintenance is a heavy charge on the resources of the nation. Next to human power, horse power is the most expensive that we can use, and we may welcome the dawn of a period when steam will, to a great extent, supplant animal power in our streets and highways.

But these, and all other extensions of steam power, involve greater consumption of coal, and we may well look with anxiety to our diminishing stock of this precious mineral, which, when once expended, can never be replaced. It will therefore, be a fitting conclusion to this address briefly to review the results arrived at by the late Royal Commission, of which I was a member, as to the extent of our available coal and its probable duration. I will not trouble you with the vast amount of detailed information collected by the Commissioners as to the extent of the British coal fields, nor with the elaborate calculations of the quantities of coal which those coal fields contain, but I will chiefly direct my observations to those points of the inquiry which fall within the province of mining and mechanical engineering, and to the broad conclusions at which the Commissioners arrived.

It being well known that a great extent of our coal lies at depths greatly exceeding those of our present deepest mines, it was essential to the inquiry that the limit of possible depth of working should be approximately defined. One of the committees, therefore, into which the Commission was divided, was entrusted with this branch of the subject, and having acted in the capacity of chairman to that committee, I am especially familiar with its proceedings. It fortunately happens that water is never met with in large quantities at great depths, and it is easy to exclude it from the upper portion of a deep shaft, by the modern process of encasing the shaft with cast-iron segments. Nothing, therefore, is to be feared on the score of excessive pumping power being required; neither would there be any practical difficulty in drawing coals from the utmost depth to which we should have to descend. Steel wire ropes tapering in thickness towards the downward end, would not be overstrained by their own weight added to the usual load, and even if the depth were carried to such an extreme as to render the strain on the rope due to its weight a serious difficulty, the alternative of drawing at two stages could be adopted.

With regard to explosive gas it might have been anticipated that the greater superincumbent weight upon deep coal would cause more gas to exude, and thereby render the workings more fiery, but this does not appear to be the case. On the contrary, the evidence given before the committee on this point was to the effect that the evolution of gas appeared generally to diminish with increase of depth. In short, the only cause which it is necessary to consider as limiting the practicable depth of working, is the increase of temperature which accompanies increase of depth. The rate of this increase of temperature is about 1° F. for every 60 feet in depth, starting from 50 feet from the surface, where the temperature is in this country 50° at all seasons. The questions involved in this increase of temperature are, at what depth would the air become so heated as to be incompatible with human labour, and what means could be adopted to reduce the temperature of the air in contact with the heated strata. A great deal of interesting evidence was heard by the Commission as to the limit of human endurance of high temperature. The natural temperature of the human body, or rather of the blood which circulates through it, is 98°. A higher temperature is the condition of fever, and the maximum of fever heat appears to be about 105°. Labour appears to be impossible, except for very short intervals when the external conditions are such as to increase materially the normal temperature of the blood. The temperature of the air may be considerably in excess of 98° without unduly heating the blood, provided the air be very dry, because the rapid evaporation which then takes place from the body keeps down the internal temperature; but if the air be humid, this counter-action does not take place, or not in a sufficient degree, and then the blood absorbs heat from the surrounding medium and the condition of fever sets in. Now, in a coal mine, the air is never very dry, and is often very moist, and we must, therefore, regard a temperature of 98° in a coal mine as the extreme limit that could be endured by men performing the work of miners. For my part, I believe this temperature is beyond the limit of possible continuous labour in a mine, and most persons familiar with the interior of coal mines will agree with me in thinking that even 90° would prove a very distressing temperature, and one which would render the cost of labour much greater than usual. However, granting the practicability of working in a coal mine in an atmosphere at 98°, the next question is, what depth would involve that temperature of the air? The depth at which the earth would exhibit a temperature of 98° would be about 3,000 feet, but it is a different question at what depth the air circulating through the mine would acquire that temperature. The air being cold when it enters the workings at the bottom of the shaft, absorbs heat with great avidity from the surfaces of the passages through which it flows. As it travels along it continues to absorb heat, but less rapidly as its own temperature increases. The rate of absorption is complicated by the superficial cooling of the passages by the contact of the air. This cooling action is necessarily greatest near the shaft, where the air is coldest, and diminishes by increase of distance, so that both the air, and surfaces against which it sweeps, become hotter as the length of the air-course is increased. The progress towards complete assimilation of temperature is much slower in the permanent air courses than at the working face of the coal, because the coal at the face being newly exposed is hotter, and therefore communicates heat more readily to the air. In any case, however, the air will eventually acquire the heat due to the depth, if its contact with the strata be sufficiently prolonged. It follows, therefore, that the temperature of the air in a mine depends on the extent of the workings as well as on the depth of the pit. But great depth involves extensive workings, because the cost of the sinking could only be repaid by working a large area of coal. Extremely deep mines will consequently possess *both* the conditions tending to produce a high temperature of the air, and unless those conditions can be counteracted by some artificial expedient, the air would acquire the temperature of 98°, assumed to be the limit of practicable labour at a depth not greatly exceeding 3,000 feet.

It is a common idea that increase of temperature may be kept down to any extent by increase of ventilation, but this opinion will not bear examination. In the first place it requires an extravagant increase of motive power to accelerate the velocity of the current of air in any considerable degree, because the resistance increases in a ratio somewhat exceeding the cube of the velocity. In fact, the only way of materially increasing the volume of air is by enlarging the sectional area of the shafts and air-courses, which would be attended both with difficulty and expense. Assuming, however, that it would be generally practicable to effect a large increase of ventilation under the conditions incident to extremely deep mining, it is necessary to consider what would be the cooling effect realised by so doing. This is a very complex question, because the reduction of temperature in the air increases the emission of heat from the strata, and because the rate of absorption is affected, not only by difference of temperature, but also by the velocity of the current.

The uncertainty on the question of the power of air to absorb heat when flowing at different velocities and in different volumes through heated air-courses, and the difficulty of reasoning out any conclusion upon the subject led me to make, for the guidance of the committee, a series of experiments in which air was forced, in varying quantities, through pipes of different lengths and sizes, immersed in hot water, the temperatures being observed at the point of emergence. In these experiments the pipes were regarded as representing, on a small scale, the air-courses of a deep mine; the hot water being the equivalent of the heated strata through which the air would be conveyed. The particulars of these experiments will be found in the appendix to the evidence taken by the committee, and the results are embodied in tables, illustrated by diagrams, which show the progressive heating of the air as it travels along the passages, and exhibit the reductions of temperature effected by successive increments of the volume of air. From these tables and diagrams it will be seen that, with short pipes, representing short distances from the shaft, increased circulation has considerable effect in lowering temperature; but with pipes representing long distances from the shaft, the cooling effect of increasing the volume of air becomes insignificant. The conclusion to which the committee came, as to the depth at which coal could be worked, is expressed in the following words :—"The depth at which the temperature of the earth would amount to 98° would be about 3000 ft. Under the long-wall system of working a difference of about 7° appears to exist between the temperature of the air and of the strata at the working faces; and this difference represents a further depth of 420 ft., so that the depth at which the temperature of the air would, under present conditions, become equal to the heat of the blood, would be about 3,420 ft. Beyond this point the considerations affecting increase of depth become so speculative, that the committee must leave the question in uncertainty; but they consider that it may be fairly assumed that a depth of at least 4,000 ft. could be reached."

The committee decline to deal with hypothetical expedients for overcoming the difficulties, but they recognised the possibility of future discovery and experience counteracting, in some unknown degree, the effects of heat and humidity in restricting the depth of working. It will, therefore, be for mining and mechanical engineers to bring all the resources of their science to bear upon this difficult problem of counteracting terrestrial heat, at depths where it approaches the limit of human endurance. The Commissioners adopting 4,000 ft. as the probable limit of practicable depth, came to the conclusion that there exists in this kingdom an aggregate quantity of about 146,480 millions of tons of available coal. If we assume that the future population of this country will remain constant, and that the consumption for domestic and manufacturing purposes, including exportation, will continue uniform at the present quantity, or merely vary from year to year without advancing, then our stock of coal would represent a consumption of 1,273 years. But if, on the other hand, we assume that population and consumption will go on increasing at the rate exhibited by the statistics of the last fifteen years, or, I might probably say, of the last fifty years, had accurate statistics been so long recorded, then the whole quantity of coal would, as shown by Mr. Jevons, be exhausted in the short space of 110 years. It will be generally admitted that the truth is likely to lie between these two extremes. The Commissioners refrained from expressing an opinion as to what the period of duration would actually be, but they presented certain alternative views of the question, resulting in periods varying from 276 to 360 years. But, all these estimates of duration have reference to the time required for absolute exhaustion of available coal, and leave untouched the important question of how long we are likely to go on before we become a coal-importing instead of a coal-exporting country. The computation of quantities made by the Commissioners, includes all coal seams exceeding 1 ft. in thickness, whatever the quality may be, and it is obvious that vast quantities of such coal can never be worked, except at a price which would render it more advantageous to purchase coal from abroad than to work it from such unfavourable beds. If, at the present time, while working our best and most available coal, our markets will barely exclude the coal of Belgium, what will be our position when driven to inferior coal more costly to work? If we look to cheaper labour for enabling us to work less valuable coal, I fear we shall look in vain; but there is one hope for a longer endurance of our prosperity as dependent on our coal, and that hope rests on the skill and perseverance of mining and mechanical engineers, who, even now, are called upon to lessen, by all the resources of mechanical science, the amount of human labour required in coal mines.

SCIENTIFIC SERIALS

THE *Monthly Microscopical Journal.*—The first paper is one of Mr. Parker's excellent studies, being on the osteology of the head of the sparrow-hawk. The first paragraph contains a generalisation which will surprise many ornithologists, for the Cariama is included among the raptorial birds; is this a result of the study of the skull? The accompanying drawings are excellent.—Dr. Royston-Piggott gives two articels, "On an Aërial Stage Micrometer," and "On the Spherules which compose the Ribs of the Scales of the Red Admiral Butterfly, and the Lepissna Saccharina."—An ingenious method of obtaining an equal illumination in both tubes of a binocular is contributed by Mr. W. R. Bridgman; and Mr. Stewart endeavours to prove that the hair follicles of the negro's scalp are curved instead of straight; he also describes clearly the framework of the sucking feet of the Echinus.—These papers are followed by abstracts of interest, including several from the American journal, the *Lens.*

SOCIETIES AND ACADEMIES

LONDON

Royal Society, Feb. 6.—"Memoir on the Osteology of Hyopotamidæ." by Dr. W. Kowalevsky. The paper is intended to fill a deficiency in our knowledge of the extinct creation by giving a complete osteology of one family of the Paridigitate Ungulate. It has been supposed that fossil representatives of this family would exhibit a less reduced skeleton and a more complete number of digits than recent genera; yet such is not the case. The genera *Anoplotherium* and *Liphodon* present in their feet the same degree of reduction as in recent Ruminants, save the confluence in a canon-bone. Notwithstanding this, they have been considered the progenitors of the Ruminantia, from a deficiency in other forms. The present paper introduces a new form, known only by the teeth till now; these, the *Hyopotamidæ*, vary considerably in specific and generic form, ranging from the Lower Eocene up to the Lower Miocene period, and in size from a rabbit to a hippopotamus. The Eocene species, except one termed *diplopus*, have not lost the lateral digits, and are included in the genus *Hyopotamus*. The division of the Ungulata into *Paridigitata* and *Imparidigitata* must have occurred about the cretaceous period, as shown by the diversity exhibited by both groups from the lowest Eocene. The former, the *Paridigitata*, split very anciently, perhaps in the chalk, into those with tubercular, and others with crescentic teeth. These groups, once separate, kept entirely apart, but frequently followed parallel lines of descent. Following these two divergent lines of descent, both groups culminate at the present time in such forms as *Phacochœrus* and *Dicotyles* for one group, and the *Bovidæ* for the other, links between these being absent. The Paridigitata with crescentic teeth will be termed *Par. selenodonta*, and those with tubercular *Par. bunodonta*. To the first group belong *Anoplotherium*, *Liphodon*, *Hyopotamus*, and others, together with the existing ruminants, whilst the second embraces the *Suina*, *Hippopotamina* and *Entelodon*. There is in some cases difficulty in deciding whether the teeth are tubercular or crescentic, the lobes being so thick.

It is important to find some osteological characters to confirm the above division, and the hand and foot from their variations suggested probable data. In tracing the Paridigitata in time, there is a marked tendency to the gradual reduction of the manus and pes, and an advantage to the individual apparently arises from the simplification. By comparison of all forms, a simple structure of the manus and pes may be obtained, such as was probably possessed by the common ancestor, and such a type is nearly retained by *Hippopotamus*, and was possessed by *Hyopotamus*. In none of these forms is the limb pentadactylate. Supposing the feet to be pentadactylate, the following is the disposition of the digits in the type:—The two outer digits (the fourth and fifth) are always supported by one bone, the unciform in the manus, and the cuboid in the pes; the three succeeding inner digits are supported each by a separated bone, the third, second and first cuneiform in the pes, and the os magnum, trapezoideum, and trapezium, in the manus. In the latter the third digit touches the unciform, and the second the magnum; the second digit of the pes touches the third cuneiform. The first digit being lost in all Ungulata, the trapezium and first cuneiform support the second digit.

Beginning with this type, which was probably exhibited by the progenitors of the Paridigitata, the reduction along both lines of descent may be followed, and in doing so a series of parallel modifications may be obtained, though it is found among the crescent-toothed line that the reduction is much more rapid than along the tubercular toothed. By reduction of the foot is meant that locomotion is carried on by the two middle toes instead of by the original four; and this seems to be an advantage to the organism, as it is exhibited by all descending lines of Ungulata. Going further into detail, it is found that both in Selenodont and Bunodont Paridigitata, a two-fold method of reduction of the manus and pes, a simple or *inadaptive*, and an elaborate or *adaptive* method is observed. In the first or *inadaptive* mode of reduction, the foot, whilst losing its lateral digits, acquires no better adaptation to altered circumstances of locomotion than is derived from the mere thickening of the remaining digits. The relation between the carpal and tarsal bones, and the remaining two metacarpal and metatarsals, remains unaltered, and the remaining digits do *not* enter into any modification by which they can receive more ample support from the carpal and tarsal bones, by taking the place formerly occupied by the reduced digits. *Anoplotherium*, *Liphodon*, and *Hyopotamus*, are examples of this method of reduction.

In the second or *adaptive* method of reduction, the middle digits grow larger and thicker than in the first mode; but while broadening transversely they do not adhere to the ancestral type, but tend to gain a support on *all* the bones of the carpus and tarsus, pushing the lateral digits to the side and thereby gaining a better and more complete support for the body. The lateral digits, being rendered useless, tend to disappear, and the remaining digits, being pressed from both sides by the carpal and tarsal bones, tend to coalesce to form the *canon* bone of recent ruminants, or of the hind foot of *Dicotyles*. In this, the *adaptive* method, modification keeps pace with inheritance, and examples of it may be seen in *Sus*, *Dicotyles*, *Hyæmoschus*, and the Ruminants.